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# THE SERRA DO ESPINHAÇO, BRAZIL

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The name Serra do Espinhaço ("Backbone Range") was introduced into geographical literature in 1822 (1) by the founder of Brazilian geology, Wilhelm von Eschwege, as a comprehensive term for the various orographic units that form a great watershed between the rivers flowing directly to the Atlantic and those that discharge first into the Uruguay, Paraná, and São Francisco. By modern usage, and in fact by the subsequent usage of Eschwege himself, the name has, however, been practically limited to the section of this watershed corresponding to the São Francisco basin, the greater part of that corresponding to the Paraná basin being known as the Serra da Mantiqueira, while the remainder of this section and the one corresponding to the Uruguay basin are considered as forming parts of the Serra do Mar range. As thus limited, the name, though robbed of much of its pristine importance and appropriateness, is applied to a well-marked orographic feature distinguished by special topographic, geologic, and tectonic characteristics.

Some of the most distinctive topographic and geologic features of the range are well set forth by Eschwege in his detailed descriptions of his various journeys in the gold and diamond districts (2) comprised in the section extending from Ouro Preto to Diamantina, the occurrence of these minerals being of itself one of the leading characteristics of the range. Thus he contrasts the greater mean elevation ($1{,}000^{m}\pm$ with peaks rising to $1{,}500$–$1{,}800^{m}$), the general plateau character with abrupt margins, the bald and rugged aspect of the peaks and minor ridges, and their general north-south trend, and the predominance of schistose rocks (especially quartz and ferruginous schists), with the lower altitude, gentler and apparently systemless topography ("like a storm-tossed forest sea") and predominance of crystalline rocks (principally gneiss and granite)[1] that characterize the adjacent zones, particularly the one lying to the eastward. The tectonic features of the range have, on the contrary, scarcely been touched upon by him or his successors.

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[1] Eschwege had a special crystalline-chemical hypothesis of his own (set forth in detail on pp. 11 ff. of his *Gebirgskunde*) regarding the mode of formation of what

Owing to its wealth of gold and diamonds, the southern section of the range, from Ouro Preto to Diamantina, has been frequently visited and described, with attempts to give an idea of its geological characteristics; but, with the exception of the writings of Eschwege, Spix and Martius (3), Helmreichen (4), Henwood (5), and Hussak (19), but little is to be found in the somewhat voluminous (as compared with other parts of Brazil) literature relating to this region that, from a geological point of view, is comprehensible, or, being so, is of permanent value. The remaining sections and the regions on either side are almost a *terra incognita* from both a topographic and a geologic point of view, and, as in all other parts of Brazil, the lack of reliable maps is an almost insuperable obstacle to detailed geologic studies. The present sketch is based on a few flying trips to the above-mentioned gold and diamond regions, a hurried and partial examination of the diamond-bearing section in the state of Bahia, a boat trip on the river São Francisco and its tributary, the Rio das Velhas, and an excursion into the region of the middle Jequitinhonha, which, however, did not extend as far as the eastern margin of the Serra do Espinhaço region. The observations that could be made on these hurried trips, supplemented by the meager gleanings to be found in the literature relating to the region, are manifestly inadequate for more than the most general treatment of the subject.

The Serra do Espinhaço, as now understood, constitutes a zone with a width of about 50 to 100 kilometers, and a mean elevation of over 1,000$^{m}$, characterized by rugged topographic features, and rising with abrupt margins a few hundred meters above the lower regions of more uniform topography on either side. It extends in

in his time were known as the primitive rocks, among which he included, as a second division, the bedded arenaceous and argillaceous rocks of the Serra do Espinhaço. He did not admit a succession of sediments among them; he did not attempt to subdivide them into series. The most unfortunate result of this point of view was the lumping-together of all the quartzose rocks of the region under the general name of "itacolumite," which has been an incubus on Brazilian geological studies. Being an acute geological observer, he did not fail to note evidences of the existence of two unconformable series of beds among the rocks so classed, but, withheld by his theory, he did not give these observations their due importance.

almost perfect parallelism with the coast-line and with the river São Francisco (above the great bend at Cabrobó), with a general northerly trend from about latitude 20° 30″ to about latitude 9°, where the river São Francisco, after making a sharp bend to the southeast, cuts through the range or, more probably, flows past its northern end. Throughout this extension of over 1,000 kilometers, this zone forms the eastern rim of the São Francisco basin, which receives the drainage of its western portion, while its eastern drainage goes directly to the Atlantic through the rivers Doce, Jequitinhonha, Pardo, Rio de Contas, Paraguassú, Itapicurú, and Vasabarris. In the upper part of the basins of the Rio das Velhas, Jequetinhonha, and Paraguassú, and to a less extent in that of the Rio de Contas also, the drainage courses correspond approximately with the north-south trend of the serra, while, after escaping from it, the Rio das Velhas and the Jequitinhonha flow for a considerable distance in general parallelism to its margins. As certain structural features are more apparent in the northern than in the southern section of the range, our examination can best be made from north to south.

The São Francisco, at some 80 kilometers below the great bend at Cabrobó, where it changes from a northeast to a southeast course, enters a zone of sandstone country which lies in the line of prolongation of the Serra do Espinhaço, though it is somewhat doubtful if it should actually be included in that range. This zone extends from near the mouth of the small river Pajahú to near the great cataract of Paulo Affonso, with a width, along an east-west line, of at least 50 kilometers, while away from the river the width appears to be much greater. The river, which above this zone flows over a bed of gneiss and granite, enters the sandstone belt at an elevation of about $330^{m}$ and leaves it at an elevation of about $300^{m}$, to again flow over gneiss, granite, and syenite, in which it has excavated a deep canyon that contains one of the most notable of Brazilian cataracts. The sandstone therefore rests on a nearly horizontal base of truncated crystalline rocks (a peneplain ?) with a mean elevation of about $300^{m}$, and rises in table-topped hills and ridges on each side to about an equal elevation, or approximately $600^{m}$ above the level of the sea.

The sandstone is moderately hard, usually coarse-grained, with frequent inclosed pebbles, which in some layers become sufficiently

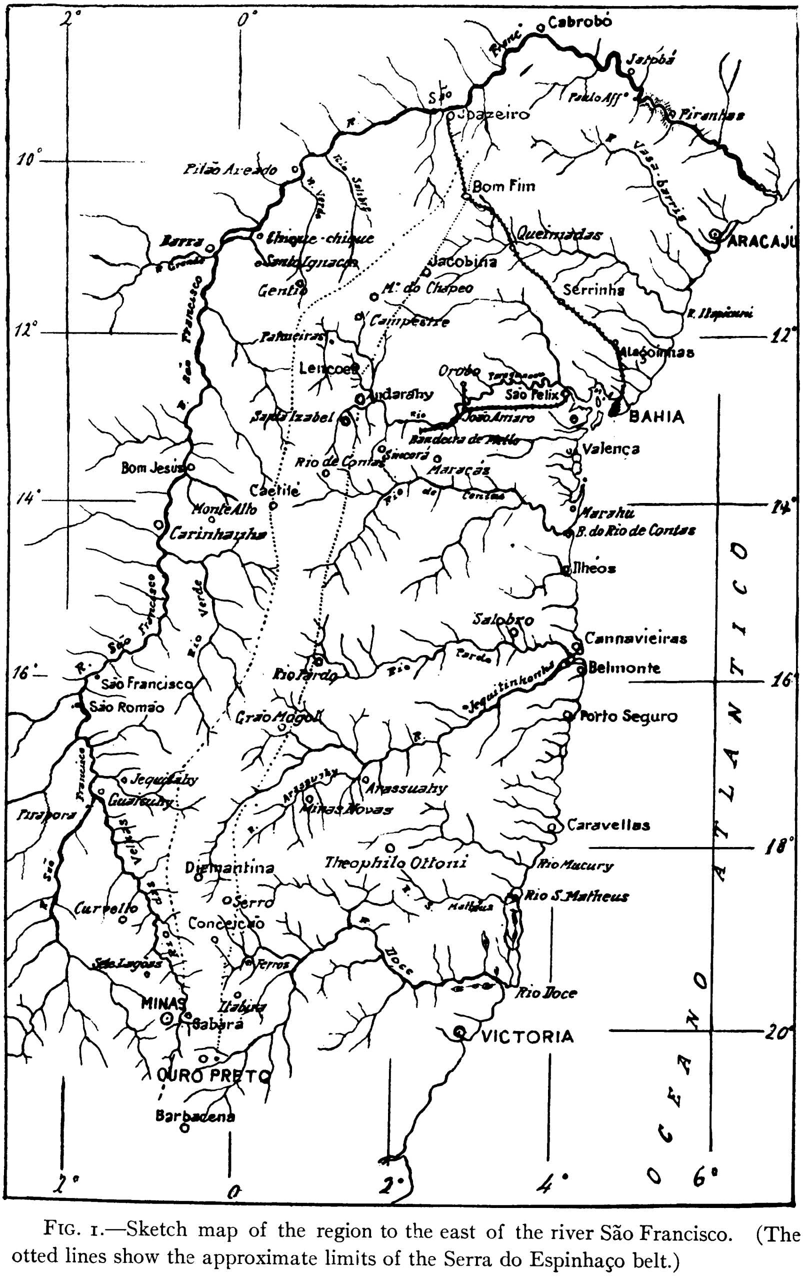

FIG. 1.—Sketch map of the region to the east of the river São Francisco. (The otted lines show the approximate limits of the Serra do Espinhaço belt.)

abundant to constitute a conglomerate. The rock is frequently argillaceous, and thin layers of marly shale appear in which at two points (Atalho and Angico, about 6 kilometers apart) I found fossil woods, cyprids, and bones, teeth, and scales of fishes and reptiles (8, 9, 10). The small collection made here was unfortunately lost, but on the occasion of making it I had the strong impression of a close relationship with the fresh-water Cretaceous fauna of the neighborhood of Bahia, based on the general aspect of the fossils, and especially on scales that I identified as *Lepidotus*. In this connection it is to be noted that the famous fossil fishes (including a *Lepidotus*) of the vicinity of Jardim, in the state of Ceará, occur at a distance of about 200 kilometers to the northeast, in front of the base of a sandstone table-land which may readily be presumed to be connected with that of the margins of the São Francisco. The sandstone beds appear at first sight to lie horizontally, but at a number of points moderate northerly dips (seldom more than 10°) were observed, but no distinct evidence of folding could be detected.

The railroad from Bahia to Joazeiro on the river São Francisco affords an undoubted section across the Serra do Espinhaço belt which is crossed near the town of Bom Fim (formerly Villa Nova da Rainha). The road, starting from sea-level at Bahia, runs for 122 kilometers in a general northerly direction to Alagoinhas (alt. $137^{m}$) through a country composed of soft Cretaceous and Tertiary strata that have been quite fully described by Hartt, Rathbun, and myself (6, 7). From this point the narrow-gauge prolongation runs in a general northeasterly direction for 452 kilometers, crossing the Serra do Espinhaço belt between kilometers 320 and 370, with a summit level of $683^{m}$, and ending at Joazeiro at an elevation of $372^{m}$, the terminal station being only slightly above the high-water level of the São Francisco at this point. In a trip over this line the following car-window observations could be made.

From Alagoinhas the road ascends for 60 kilometers over horizontal beds of soft sandstone to an elevation of $406^{m}$. Up to the $200^{m}$ level the beds are quite argillaceous and gritty, and a water-bearing horizon occurs here which probably marks a break in the stratification, since the beds above this level are more sandy and porous, generally deeply stained by oxide of iron, and in general of quite different aspect from those below. At kilometer 29 (elevation 281$^{m}$), near the station of Uruçanguinhas, a soft ochrous shale, containing beautifully preserved fossil leaves, appears in a cutting. Collections of these fossils were remitted some years ago to Sapota and Ettenhausen, but both unfortunately died before reporting upon them. It is understood, however, that they were considered to be of late Tertiary, probably Pliocene, age. The western face of this Tertiary plateau presents a thickness of about 80$^{m}$ of strata, as gneiss appears in a stream-bed at kilometer 85 at an elevation of 322$^{m}$. From this point to Jacuricy station (kil. 245) the road crosses a plateau of a general elevation of about 400$^{m}$, dotted with detached

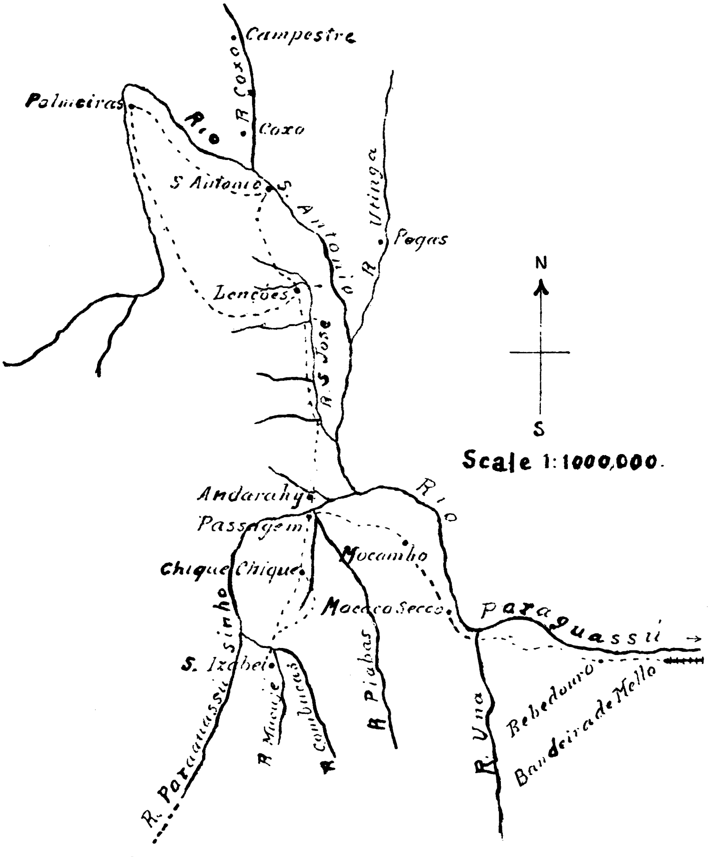

FIG. 2.—Sketch map of upper Paraguassú basin.

knobs and ridges. The soil cap is generally thin, gneiss and granite rocks appearing underneath it. With these occur considerable stretches of a black schistose rock, which is presumed to be mica or hornblende schist. A considerable part of this section of the road is along the watershed between the Paraguassú and Itapicurú, descending afterward to the valley of the latter. To the westward of this comparatively level section rises (kil. 257; alt. $343^m$) the Serra de Itiuba, a bold ridge of red granite estimated to be about $800^m$ high. The road crosses it in a gap at an elevation of $437^m$, and descends to the river Itapicurú (kil. 280) at $354^m$, and then ascends over gneiss and granite to the city of Bom Fim (kil. 320), on the flank of the Serra do Espinhaço, at an elevation of $548^m$. On the ascent to the summit (kil. 355; alt. $683^m$) the cuttings are in granite to kil. 333, where flaggy quartzites begin to appear and continue, with occasional interruptions of granite, to Angicos station (kil. 383; alt. $487^m$), which is a little beyond the western base of the serra. From Angicos to the end of the line at Joazeiro (kil. 450; alt. $372^m$) the country is a gradually sloping plain, so slightly accidented that for 60 kilometers the road has been laid out on a perfectly straight line. Scattered knobs and ridges of granite, gneiss, and quartzite rise abruptly above the general uniform level. The rocks seen from the foot of the Serra do Espinhaço to kil. 391 (alt. $490^m$) are gneiss and granite, with occasional outcrops of quartzite. From this point to kil. 430 (alt. $416^m$) the surface rock is a whitish limestone in horizontal beds, and of only a few meters' thickness. The aspect of the rock is that of a fresh-water deposit, and though no fossils could be found, it is presumed to be of Tertiary, or possibly Quaternary, age. A similar limestone is known to occur higher up the river in the neighborhood of Chique-Chique, where it appears to cover a considerable area. Along the last 20 kilometers of the road gneiss and granite reappear.

A recent excursion to the diamond region of the upper Paraguassú basin gave me an opportunity to examine the section characteristic of the valley of that river. The trip was made by the Bahia Central Railroad to its terminal station, Bandeira de Mello, situated about 100 kilometers, by the river, to the east of the point where it escapes from the serra at Passagem (see annexed sketch map), the remainder being made on mule-back. The railroad, starting from São Felix near the mouth of the river, rises at once with a heavy grade to the top of a gneiss plateau with a general elevation of 200 to 300$^{m}$, over which it runs in a line parallel to the river and about 20 kilometers to the southward of it to kil. 165, where it again meets the river and follows its margin to the terminal station at kil. 259. The gneiss plateau away from the river is remarkably level, but dotted with isolated knobs and ridges that for the most part seem to be composed of granite, which also appears in numerous bare ledges that do not rise perceptibly above the general level of the plain. Except in the eastern part, about the headwaters of a small river draining directly to the sea, and apparently in a zone of abundant rainfall, the soil-cap is very thin, often lacking. In this respect, and in the general evenness of the surface, the western part of this plain, like those above described along the São Francisco road, seems to offer a good example of the formation, under arid conditions, of plains by the truncation of strata that normally would present a strong relief.[1] The section accompanying the river is bordered by gneiss

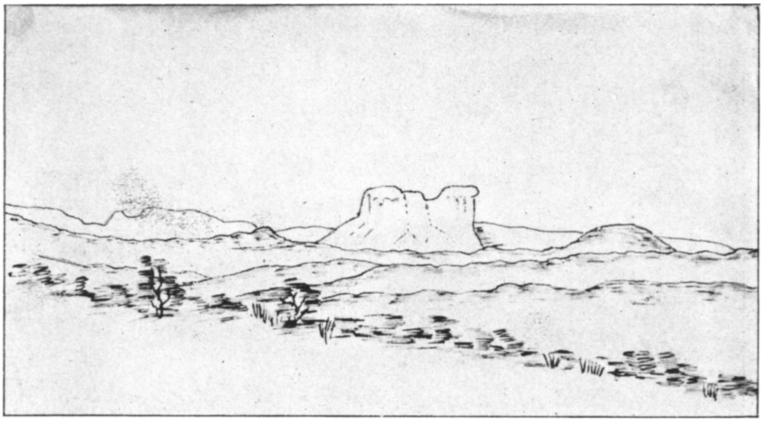

FIG. 3.—Profile near Lençoes.

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[1] See discussion of subaërial denudation in an arid climate, by Professor W. M. Davis, in *Journal of Geology*, No. 5, 1905. No reliable data regarding the mean annual rainfall in the districts here considered could be obtained, but it is tolerably certain that it is less than a meter, and that the minimum is often less than half a meter. With the exception of the Paraguassú and the streams of the Serra do Espinhaço belt, all streams dry up, or become reduced to strings of pools during several months of each year.

and granite rising a few hundred meters above the level of the river, and here the traveler cannot form an adequate idea of the general topographic features of the region, which, however, appears to be considerably higher than that along the first section of the line. The terminal station, Bandeira de Mello, is at an elevation of about $300^m$ above the level of the sea, in the midst of gneiss and granite hills that rise about as much higher.

About 20 kilometers to the westward of the end of the railroad begins a region of sedimentary rocks that includes the whole of the upper part of the Paraguassú basin. Near the river this region begins at Bebedouro with an escarpment of sandstone and limestone rising some $250^m$ above the level of the stream to a plateau of a mean elevation of about $600^m$. Behind this rises a second plateau of sandstone to a mean elevation of $1{,}000^m$ or more, and constituting the Serra do Espinhaço proper, or, as it is here known, the Chapada Diamantina ("Diamond Table-Land"). To the northward of the Paraguassú the margin of the serra is marked by the river São José, which escapes from it near Lençoes and flows along its base. On the south side of the Paraguassú this margin makes an offset to the eastward as far as Mocambo, thus causing a great bend in the river,

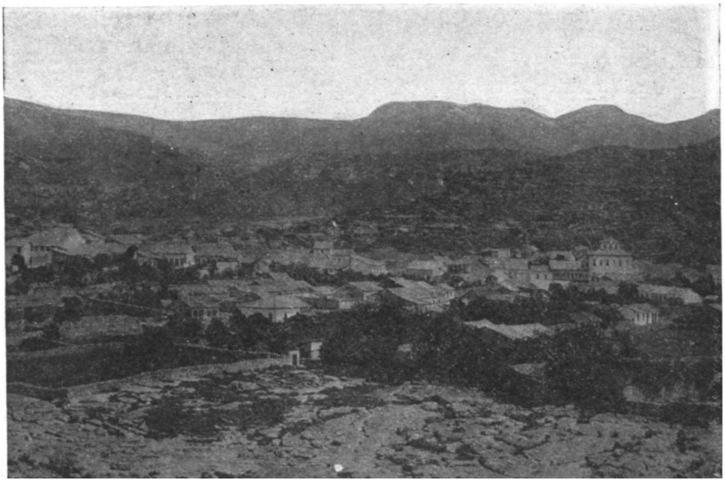

FIG. 4.—View of Santa Isabel do Paraguassú.

and from there extends southward in a high ridge between the small rivers Piabas and Una. This upper sedimentary part of the Paraguassú basin is of rectangular shape, with its longest axis lying in a north-south direction, and thus perpendicular to the general west-east course of the middle and lower portions. It is characterized topographically by secondary valleys extending from south to north and from north to south, which unite their waters below Passagem, and where the main valley assumes a general easterly direction.

The geological structure of the first and lower plateau is fairly well seen along the road from Bebedouro to Mocambo. At the first locality a fine escarpment, that extends southward as far as the eye can reach, rises abruptly from the right bank of the river to an estimated height of $250^m$. The base is composed of a horizontally bedded, coarse, reddish sandstone. On a trail leading back among the hills the sandstone is seen to rise to about $20^m$ above the river, intercallations of micaceous sandy shale appearing near the top. The section is then interrupted for a further rise of $40^m$, and then comes a magnificent bluff of light-blue flaggy limestone about $40^m$ high. Some of the layers are full of cherty nodules, which on weathering out of the rock afford a means of tracing it where concealed by a soil-cap. At the Cachoeira do Funil, 6 kilometers above Bebedouro, a similar escarpment, that stretches away to the northward, appears

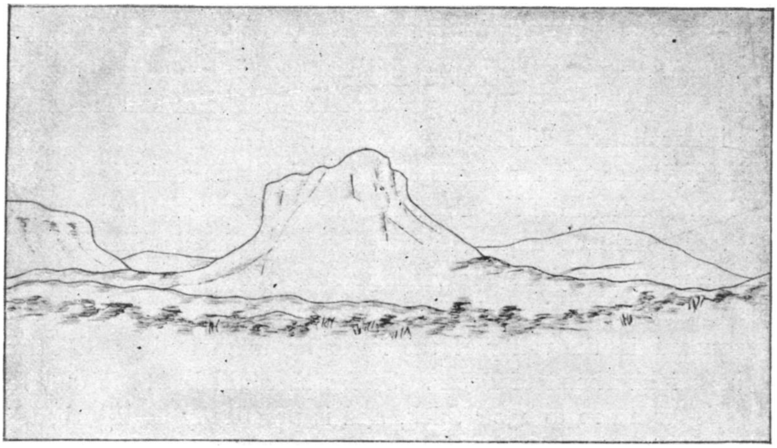

FIG. 5.—Profile near Santa Isabel.

on the northern side of the river, and the base of the sandstone is seen to consist, for a thickness of a few meters, of a coarse conglomerate containing pebbles and bowlders of gneiss and granite. At one point the conglomerate is seen to rest on granite. The road then ascends, over a chert-strewn trail, a table-topped ridge known as the Serra das Araras, which is said to abut on the river in a fine limestone bluff. On the top of this ridge the aneroid indicated an elevation of $575^{m}$. Small outcrops of limestone occur on the western descent to the river Una, where just below the bridge is another limestone bluff $35^{m}$ high. The beds here, as at Bebedouro, have a slight westerly dip of 5–10°. On the ascent from the river Una the road passes over about $100^{m}$ of strata above the limestone, but no rock *in situ* appears. Cherty nodules appear in three distinct zones, and the underlying rocks are presumed to be shales and sandstones with intercallations of limestone.

A diligent search for fossils both at Bebedouro and Rio Una was fruitless, although the limestone seems very favorable for preserving them. Limestone is reported to occur near the head of the Rio Una, and the valley of this small river is presumed to be almost exclusively occupied by this series, which also appears to the northward of the Paraguassú in the valley of the lower Santo Antonio, and Utinga in the neighborhood of Pegas. So far as could be made out, this series is from 200 to $250^{m}$ thick, and is practically undisturbed, or at all events much less so than the strata in the adjacent Serra do Espinhaço zone. About a quarter of the thickness, and perhaps much more, is composed of limestone which is characteristically cherty, at least in many of its layers.

From Mocambo to Passagem the road passes, at an elevation of $600^{m}$, over a ridge that rises considerably higher to the southward. The rather unsatisfactory rock exposures consist of sandstone, in places lying horizontally, in others with a moderate dip to the eastward or to the westward. The section along the road seems to be across the expiring end of a fold which to the southward forms a high ridge known as the Serra do Sincorá, on the eastern margin of the Serra do Espinhaço plateau. An appearance, as seen from a distance, of synclinal structure in the valley of the Piabas, on the western flank of the supposed fold, confirms this interpretation.

The serra front between Chique-Chique and Lençoes is constituted by a heavy series of sandstone beds dipping eastward at an angle of about 30°, and rising from a minimum elevation of $330^{m}$, in the bottom of the valley at Passagem, to a crest line of $1,100–1,200^{m}$ Passing over the crest on the road from Chique-Chique to Santa Isabel, flat-lying portions and westerly dips were observed. Westerly dips also occur on the road leading northward from Lençoes to Palmeiras, and about the latter place. The details of the structure could not be worked out, but it is evident that a great sandstone sheet is here bent into broad anticlinal folds. Apparently the main fold of the district begins with a narrow end to the northward of Lençoes, broadens out southward, and narrows down again near Santa Isabel, where it becomes confused with other folds. The combined valleys of the São José and Chique-Chique are excavated along the strike of the softer upper beds of the eastern wing of this fold, laying bare a group of harder quartzitic and conglomeratic beds that occur near the middle of the series. The most prominent member of this group is a thick bed of coarse conglomerate that is diamond-bearing, and in consequence of the topographic disposition of the strata, the entire serra front from Lençoes to Chique-Chique is marked by an almost continuous line of active or abandoned diamond-washings.

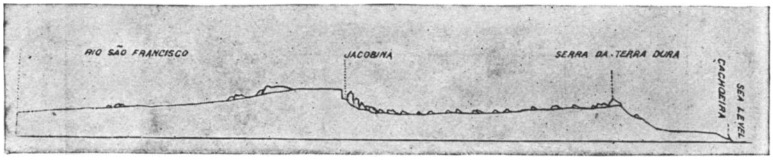

FIG. 6.—Profile of the route from the São Francisco to Bahia, by Mr. J. A. Allen.

Over the top of the plateau, which, as already stated, has a mean elevation of $1,000^{m}$ or more, the sandstone sheet is much broken up into detached blocks, as shown in the annexed outlines traced from photographs, and in the view of the town of Santa Isabel which I owe to Dr. Henry Furniss, United States consul at Bahia. The escarped margins of these blocks, and other phenomena in the district, are at times suggestive of faulting, but, however important this may have been in determining minor features, it is evident that the main tectonic features of the region have been produced by folding and denudation.

The sandstone sheet, estimated to be from 400 to $500^m$ thick, consists of a lower flaggy, reddish portion, well seen in the blocklike hills about Santa Isabel, succeeded by a coarse conglomerate that passes to a whitish sandstone with scattered pebbles and patches, and layers of conglomerate, and finally to argillaceous sandstones and sandy shales. The conglomerate, where seen in contact with the lower red sandstone, contains large fragments of this rock that indicate a time-break and unconformability, at least of overlap, between the two. Some of the sandstone layers next to the conglomerate are very hard and quartzitic, but in general both members of the series are unmetamorphosed. The lower member may take the name of the Paraguassú group, as it is especially well developed in the vicinity of Santa Isabel (or São João) do Paraguassú. The upper member may appropriately be denominated the Lavras group, as its conglomerate member is undoubtedly the principal, if not the only, repository of the diamonds that have given the popular name of Lavras ("Washings") to the whole district. The thickness of the Paraguassú group can be estimated with approximate accuracy at about $250^m$; that of the Lavras group cannot be so closely calculated, but it is probably about the same.

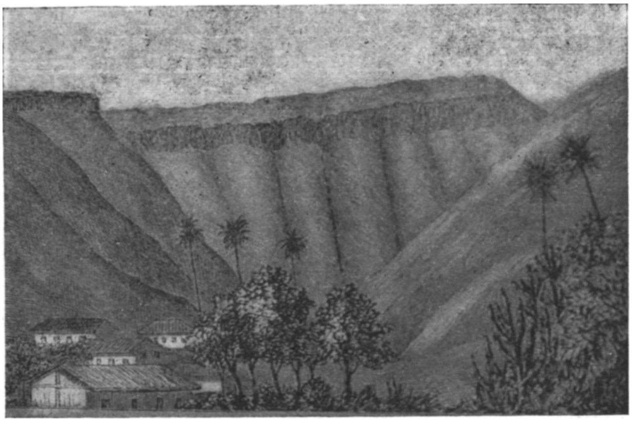

FIG. 7.—The Tombador (Tumble Down) near Jacobina, by Mr. J. A. Allen.

With the exception of the sandstone blocks above mentioned, the pebbles of the conglomerate, seen by the thousands in hundreds of square meters of clean-cut fractures passing through them, are exclusively of quartzite. These represent an older formation, to be mentioned farther on, which is known to occur in other sections of the Serra do Espinhaço and which may be presumed to occur also in the Paraguassú section to the westward of the region here described. The central portion of the range in this section and the country to the westward are very imperfectly known, but the recurrence of diamond camps justifies the presumption that the Lavras conglomerate recurs frequently, through folding, over a great part of it. The westernmost of these camps is in the Serra de Assuruá, a detached mountain ridge near the river São Francisco. Burton (20), who visited it, mentions the occurrence of a coarse conglomerate, which he compared to the Old Red Sandstone of Scotland.

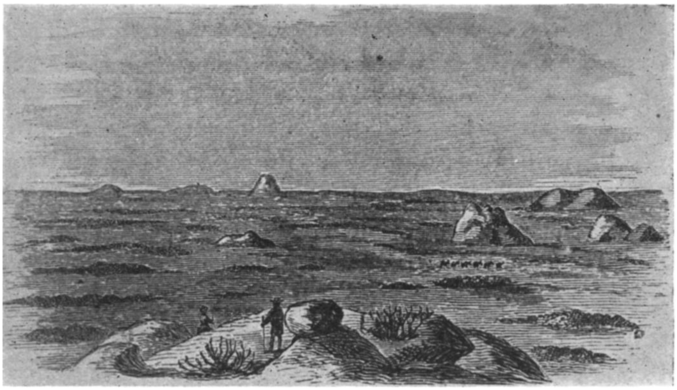

FIG. 8.—View on the gneiss plain of Bahia, by Mr. J. A. Allen.

Another section, intermediate between the two above described, across the range and the adjacent country on each side, is given in an interesting note by Mr. J. A. Allen, published in Hartt's *Geology and Physical Geography of Brazil.* Mr. Allen's route was from Chique-Chique on the São Francisco to Bahia, passing by Jacobina, and thus about 100 kilometers to the southward of the first railroad line above described. His profile of the route and sketches of characteristic line of travel as being essentially over three distinct plateau regions, a limestone plateau to the westward, a sandstone one in the central or Serra do Espinhaço region, and a gneiss one to the eastward. The last presents a remarkably level aspect, being apparently everywhere of nearly uniform altitude, but is dotted with isolated, abruptly rising points and knobs, as shown in the annexed sketch. The soil-cap is thin, and often entirely absent, over areas of several acres in extent.[1] In the serra zone a horizontal sandstone gives rise to a beautiful level, grassy plain occupying the summit of the watershed. To the eastward this table-land breaks down abruptly in precipitous cliffs, to the lower gneiss country, but to the westward the slope is more gradual to the limestone plain, and across this to the São Francisco. Above the generally level surface of the latter rise irregular pinnacled hummucks and low serras. The limestone is highly inclined, and in one place was seen lying unconformably under horizontal beds of sandstone that stretched away southward like a vast level floor. Near the western base of the serra two large hills of hornstone or chert were crossed.

From the general topographic features of the Serra do Espinhaço zone it would be natural to assume that the sandstone sheet of the Jacobina region should be considered as the northern prolongation of that of the upper Paraguassú district, which, with its characteristic diamond contents, certainly extends northward as far as Morro do Chapeo, or about two-thirds of the intervening distance between Lençoes and Jacobina. In this case it has remained unfolded in the northern end of the zone—a seemingly improbable hypothesis; or the evidences of folding escaped Mr. Allen's observation, which also seems unlikely, as his sketch confirms his description. Moreover, unfolded sandstones occur in the region at no greater distance away than those of Lençoes, as shown in the annexed sketch by Dr. Theodoro Sampaio of a table-topped ridge, $750\pm^{\mathrm{m}}$ high, above

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[1] Mr Allen describes singular holes in the rocks of this region, which are usually filled with water and known as *caldeirôes* ("pot-holes"), and states that nearly all of a considerable number examined prove to be genuine pot-holes, some of which were of great size. These are probably of the same nature as the caverns, looking like gigantic swallows' nests in a clay bank, seen on the granite knobs along the Bahia Central Railroad. So far as could be judged from distance, these are due to a peculiarly localized action of disintegration. Those seen, however, were on the sides of hills and would not hold water.

Joazeiro and close to the São Francisco, and which he informs me is composed of horizontal beds of sandstone and conglomerate overlying inclined quartzite. The topographical features and the elevation of this ridge, as of others in the vicinity, are suggestive of the Cretaceous plateaus of the lower São Francisco and of the states of Ceará and Piauhy, and there is nothing improbable in the hypothesis that these (coming from Piauhy) extend into this region. This hypothesis would become a certainty if one could accept unreservedly the statement of M. Liais (21) that at a place called Engenho, somewhere near the western base of the Jacobina serra, he found nodules of argillaceous limestone containing scales of *Lepidotus*, a ganoid tooth, and gasteropod shells which he identified as *Paludina* and *Planorbis*. These fossils, with the exception of the shells, are very suggestive of those of the fish-bed of Ceará, which have been carried far and wide over the country, and in part probably over this very road. On the other hand, experience elsewhere has shown that the statement of this author must be taken with caution. Still there is no inherent improbability in the hypothesis that the fossils may have been found *in situ* as stated.

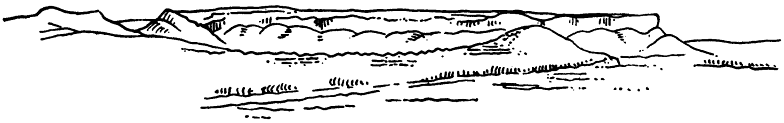

FIG. 9.—Serra do Encaibro (Ridge Pole), seen from the river São Francisco.

In the region to the west of the serra Mr. Allen seems to have generalized his observations on inclined limestones to all of those seen along the road. It is certain that horizontal beds of limestone like that above mentioned in the vicinity of Joazeiro occurs at and about Chique-Chique, and, as in other parts of the São Francisco basin, it is probable that both horizontal and inclined limestones occur among the older rocks. The chert-strewn hills are suggestive of the series to the east of the serra in the Paraguassú basin.

Another line of travel across the Serra do Espinhaço region in the state of Bahia lies to the southward of the Paraguassú route above described, and passes by Maracás, Sincorá, Villa do Rio de Contas, Caetité, and Monte Alto, to Caranhanha on the river São Francisco.

Some interesting information regarding the topographic and geologic features of this route can be gathered from the narrative of Spix and Martius (3), and from the report of Dr. Theodoro Sampaio (22). The road, starting from São Felix, is for some distance nearly coincident with the railroad line above described, and over a gneiss plain of moderate elevation. It then rises to the top of a higher gneiss and granite plateau at Maracás, at an elevation of about 1,000$^{m}$, that occupies the watershed between the rivers Paraguassú and Rio de Contas. This plateau, according to Dr. Sampaio, breaks down to the westward in a wall-like face about 350$^{m}$ high which overlooks an undulating region with detached hills that intervenes between it and the Serra do Sincorá, the eastern front of the Serra do Espinhaço plateau. This region is also composed mainly of gneiss and granite, but about the headwaters of the Rio Una a zone of reddish shale and ash-colored limestone intervenes between the crystalline rocks and the sandstone and conglomerate of the Serra do Sincorá. The Serra do Espinhaço section of the road, extending from the south end of the Serra do Sincorá to beyond Caetité, is mainly over a highly inclined series of quartzites and argillaceous schists, which Spix and Martius identified with those of the gold districts in Minas Geraes (this region is also auriferous), with occasional exposures of gneiss, micaschist, and granite. To the right of the road, and forming the highest points of the region, these older rocks are overlain by a conglomeritic sandstone, which Spix and Martius referred to the Rothtodtliegende, and which evidently represent spurs and outliers of the sandstone sheet of the adjacent upper Paraguassú basin. The western face of the plateau, known by the local name of "Serra Geral," is abrupt, but of no great altitude (850$^{m}$) at the watershed near Caetité, where it is composed of gneiss. To the west of the mountain front the road is over a nearly level plain of truncated granite, gneiss, quartzite, and limestone rocks, but with isolated knobs and ridges rising above the general level.

To the south of the Rio de Contas road to Grão Mogol, in the state of Minas Geraes, a distance of about 300 kilometers, but little is known of the Serra do Espinhaço plateau beyond the fact that diamonds occur in several localities. For the section about the northern headwaters of the Jequetinhonha in the neighborhood of the diamond-mining town of Grão Mogol, Helmreichen (4) has given an excellent description, accompanied by a geological section of his route from the middle Jequetinhonha across the serra to the Rio Verde.[1] According to this description and section, the Serra do Espinhaço is here a broad mountain plateau, which rises abruptly above lower plateaus on either side. The eastern plateau consists of truncated strata of micaceous gneiss and micaschist with, near the foot of the serra, intercallations (outlyers ?) of quartzite; the western one, of truncated inclined beds of grauwacke and limestone. The central, or Serra do Espinhaço, plateau consists of an undulating central portion of various schists, including gneiss and quartzite, with patches of granite and hornblende rock, above which rise ridges of quartzite which is frequently conglomeritic,[2] and in which diamonds occur—a circumstance that has given great importance and interest to the locality of Grão Mogol. From specimens that have come to hand, and from information given by two excellent geological observers, Drs. Francisco de Paula Oliveira and L. F. Gonzaga de Campos, it is clear that (as in 1882 I predicted would eventually prove to be the case), (12), the section at Grão Mogol is essentially identical with the one at Diamantina, which will now be considered.

In the neighborhood of Diamantina the range also consists of a broad mountain plateau, with a mean elevation of 1,200 to 1,300$^{m}$, rising abruptly above lower plateaus on either side. In the one to the eastward truncated strata of gneiss and micaschist, full of quartz veins that are frequently auriferous, have been leveled up to about the 900$^{m}$ line by horizontal beds of soft sandstone which cover an extensive area in the valleys of the Jequetinhonha and its tributary, the Arassuahy, forming table-topped hills and ridges between the valleys which have been cut from 200 to 300$^{m}$ below the level of the plain. Hartt, who visited this region in 1865 (6), correlated these beds with the Tertiary series of the coast, and cited them as evidence of a general uplift to the amount of about $1,000^{m}$. There is, however, no evidence that they are of marine origin, and it seems much more probable that they were deposited in a closed inland basin, which extends for a long distance down the Jequetinhonha valley, but is probably cut off from the lower-lying coast Tertiary series by a high zone of older rocks. In this case the evidence of uplift is given by the depth to which the valleys have been excavated below the surface of these beds, rather than by their elevation above the level of the sea, and its amount ($250 \pm ^{m}$) accords fairly well with that indicated by the coast Tertiary beds themselves.[1] The sandstone beds are often quite thin, and probably nowhere more than $100^{m}$ thick.

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[1] This section is along a zigzag line which in part accompanies the strike of the strata. Thus, while it gives a transverse section of the range, it fails to give an accurate idea of the relative width of the different zones.

[2] Helmreichen, following Eschwege, lumped all the quartzites of the region together under the name of "itacolumite," and interpreted the pebbles in the conglomerate as concretions or segregations. For this reason, although he clearly described and figured evidences of unconformability between two distinct series of quartzites, he did not interpret them as such, and thus his otherwise excellent description of the region loses much of its value from a geological point of view.

The plateau to the west of the Serra do Espinhaço, with a general elevation of 800 to $900^{m}$, also shows truncated folds, but the strata here consist of shales, sandstone, and limestone thickly threaded with quartz veins. Farther west, and near the São Francisco, appear table-lands of horizontal sandstones and shales of about $800^{m}$ elevation. Silicified dicotyledinous wood occurs in some of these beds, which are presumed to be of Cretaceous age.

The central plateau, or Serra do Espinhaço proper, shows along both flanks of the Diamantina section heavy beds of quartzitic sandstone, which dip sharply to the east on the eastern flank and to the west on the western (11, 12). Over the central part the dips are gentler and more variable, the beds in places being nearly horizontal. Over large areas the sandstone has been completely denuded away, revealing an underlying series of quartzites and argillaceous schists, with in one place a considerable patch of granite. As in the Paraguassú and Grão Mogol sections, there is here abundant evidence that the sandstone is the source of the diamonds that characterize the region. A number of the workings are in decomposed conglomeritic portions of the sandstone sheet, and at Grão Mogol diamonds have been found in the sound rock as well.

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[1] See Branner (18), who traced the coast Tertiary beds to the summit level of the Bahia and Minas Railroad in the Serra dos Aymores. The altitude is not given, as the railroad levelings were not obtainable, but by my aneroid readings it cannot be much over $200^{m}$. Along the Bahia and São Francisco Railroad, as noted above, the Tertiary beds rise to $400^{m}$, or a little more; but here the upper portion is of fresh-water origin, and perhaps much later than the lower beds, which correspond better in character with those along the Bahia and Minas line. In the basins of the upper Rio Doce in Minas Geraes, Tieté and Parahyba in São Paulo there are high-lying fresh-water Tertiary basins, with fossils, that seem to correspond with the one above considered.

The southern section of the range, forming the head of the Rio Doce basin, being in a region of very abundant rainfall, is much more deeply eroded than those above described, and along the usual lines of travel, which are parallel to its trend or cross it in deep gaps, its tectonic features are not clearly apparent. The central zone is occupied by great ridges, or blocks, of quartzites, or quartzitic sandstone, rising to an elevation of 1,500 to 1,900$^{m}$, and which, being comparatively barren of gold and of difficult access, are almost completely unexplored. These seem to represent a great sheet like that of the Jequetinhonha and Paraguassú sections, which on the lower grounds has been completely swept away, or so denuded as to be difficultly recognizable, especially as a very similar rock occurs as a member of the underlying formation. The latter consists of a great series of essentially argillaceous and micaceous schists, with intercallations of flaggy micaceous quartzites, ferruginous quartzites (itabirites), and limestones, which is frequently gold-bearing. In the bottom of some of the valleys gneiss, micaschist, and granite appear, and these are the predominant rocks in the region to the eastward of the serra, which is, however, so imperfectly known that the eastern margin of the Serra do Espinhaço zone cannot be satisfactorily traced. The western margin, as in the Jequetinhanha section, is abrupt and overlooks a similar region of truncated sedimentary rocks, which, however, throughout a considerable part of the section is separated from the base of the serra by a zone of granite and gneiss.

From the above sketch it appears that the Serra do Espinhaço consists of a basement complex of metamorphic and eruptive rocks overlain unconformably by one or more series of sandstone strata that have been disturbed by a system of northward-trending folds, whereas in the mountainous region of southeastern Brazil, of which it is an offset, the dominant trend is northeastward. In the southern sections (Jequetinhonha and Doce) the orographic movement producing the folds has also produced a certain amount of metamorphism in the form of shearing and granulation, accompanied by the development of mica, giving the rock an appearance so similar to that of the quartzite members of the underlying metamorphic series that the two have been very generally confounded under the name of "itacolumite." In these sections, however, outcrops occur, as in the neighborhood of Diamantina, in which the rock is a typical unmetamorphosed sandstone or conglomerate; and it is now clear that metamorphism, when it exists, is a local, not a general, characteristic.

Regarding the age of the Espinhaço uplift, and of the beds affected by it, no satisfactory evidence is at hand, as thus far no fossils have been found in these beds, or in others whose relations to them have been clearly established. Up to the present all writers who have treated of the region, myself included, have considered it to be very ancient, Archean or early Palæozoic. This opinion was based largely on the metamorphism of the rocks in the Diamantina and Ouro Preto districts, and, in my own case, partly on the fact that in other parts of Brazil the epoch of folding and metamorphism on a large scale could be proven by fossil evidence to be pre-Devonian. Both of these arguments are evidently weak, and must now be put aside in view of the unmetamorphosed and comparatively modern aspect of the folded rocks of the Bahia section of the Serra do Espinhaço, and of the possibility of local disturbances affecting rock of Devonian or later age. In the coast regions of the states of Bahia, Sergipe, and Alagoas there are evidences of such disturbances which have some bearing on the question here considered.

On the lower Rio Pardo, Hartt (6) found a series of inclined conglomerates, sandstones, and shales, with obscure plant remains which he referred to the Devonian, and noted indications of the presence of the same series on the lower Jequetinhonha as well. In a recent excursion in this region I found that this series occupies a zone several kilometers wide, and was informed that to the westward there is a considerable zone of limestone (marble). Owing to the high state of the river, I missed seeing the fossil locality. The conglomerate also occurs at Salobro, about a league distant from the margin of the Rio Pardo, and here it is diamond-bearing (the so-called Cannavieiras diamond district), presenting considerable resemblance to the diamantiferous conglomerate of the upper Paraguassú region. The occurrence of this series on the Jequetinhonha was confirmed by Dr. Joaquim Bahiana, a competent geological observer, and it evidently occupies a considerable belt along the eastern margin of the gneiss plateau. Branner (17) has described a similar fringe of presumably Palæozoic strata in the states of Sergipe and Alagoas, and I have seen traces of it to the northward of the city of Bahia in the neighborhood of Inhambupe. The fossils reported by Hartt were fragmentary and unsatisfactory, and his reference of them to the Devonian can only be considered as provisional. It is highly probable, however, that the series is Palæozoic, and certainly not older than the Devonian. On the other hand, the uplifted strata (consisting of conglomerates, sandstones, shales, and limestones) of Sergipe and Alagoas are certainly pre-Cretaceous.

The limestones of the upper São Francisco basin appear to represent, as Eschwege (2) has already indicated, two distinct geological formations which have not yet been discriminated. A part of them is certainly included in a disturbed series of sandstones and shales which is almost certain early Palæozoic and presumably older than the Espinhaço uplift; another part lies horizontally, at least in places, and is presumably newer. At Bom Jesus da Lapa, on the right bank of the São Francisco and almost due west from Rio de Contas, I found, in 1880 (8, 9, 10), badly preserved fossil corals of the genera *Favosites* and *Chaetetes* (?), which indicate middle or upper Palæozoic age (Upper Silurian to Permian). Possibly this limestone can be correlated with that above described to the east of the serra, but nothing definite can be said on this head. If, as above suggested as possible, the sandstone of the Jacobina region proves to be folded and of Cretaceous age, the question of the age of the uplift would be decided as Cretaceous or post-Cretaceous; but it hardly seems probable that this will prove to be the case.

The rocks entering into the composition of the Serra do Espinhaço fall naturally into three groups, each of which will probably eventually have to be subdivided into two or more. These are: (1) the gneisses and micaschists; (2) the schists, quartzites, and limestones of the auriferous regions; and (3) the quartzites and sandstones of the diamantiferous regions. With these are associated granites and other eruptives which apparently have not penetrated into the upper series and presumably antedate it.

As Eschwege has already remarked, gneiss and micaschist only appear in the lower levels of the Serra do Espinhaço zone, while, with their associated eruptives, they form the main mass of the mountains to the eastward and southward belonging to the Serra do Mar and Serra da Mantiqueira systems. These rocks have been but little studied in the region here discussed, but, so far as known, they correspond with those of the other parts of Brazil, and can safely be considered as of Archean age. It also seems tolerably safe to consider the great majority of the Brazilian gneisses (at least those that from their resistance to decay are most in evidence) as sheared eruptives, the original types being granites, norites, diorites, etc. A part of the micaschists are also of eruptive origin, but presumably the larger part will prove to be metamorphosed sedimentaries. In the part of Brazil here considered these rocks form a great shield-shaped area in eastern Minas Geraes and Bahia (with the adjacent states of Espirito Santo and Rio de Janeiro), which for the most part has been dry land since Archean times. About its borders, particularly on the west, and over its lower-lying portions the later sedimentary deposits have been laid down.

The schistose series of the Serra do Espinhaço and adjacent regions, which may conveniently be denominated the *Minas series*, consists of a great complex of predominantly argillaceous schists, with subordinate masses of ordinary quartzites, ferruginous quartzites (itabirites passing to pure iron ores), and limestones. All of these rocks are greatly sheared, and characterized by a greater or less development of a mica-like mineral (biotite, sericite, micaceous hemetite, chlorite, talc, etc.); and as in general they are much decomposed, there is great difficulty in distinguishing the different members (except the quartzose and ferruginous ones), and thus far no successful attempt to work out the order of succession in them has been made. It is tolerably certain that the quartzose, ferruginose, and calcareous members are repeated at various horizons, and eventually they will serve as reference lines for establishing the subdivisions of the series; but before this can be done the repetition due to folding and faulting must be determined and taken into account. Apparently the whole series has been bent into closely appressed overturned folds, and doubtless it has been much faulted. Until the region, or at least a typical portion of it, has been accurately mapped, any attempt to determine its detailed structure is hopeless.

The argillaceous members of the Minas series include micaceous (mainly, if not exclusively, sericitic) schists, calc schists, graphitic schists, chloritic schists, and talc schists. A considerable part, if not the whole, of the last two types consists of undoubtedly sheared and metamorphosed eruptives, and I have elsewhere attempted to show (13, 14) that a part of the sericitic schists are of the same origin.[1] There can be no doubt, however, that the greater part of the series is of sedimentary origin. Its age can only be guessed at, but it seems tolerably certain that it cannot be younger than Cambrian, and that it may be older.

The Minas series has always been regarded as the characteristic formation of the Serra do Espinhaço, and it is certain that it, or another series very like it, appears throughout the entire length of the range. To the northward of the Rio Doce section the characteristic ferruginous and calcareous members seem to disappear in the zone of the serra, though they occur again on the banks of the São Francisco between Urubú and Joazeiro. It seems probable, therefore, that more than one geological series is here included. It is also certain that these characteristic members occur on both sides of the Rio Doce section at considerable distances from the reputed margins of the Serra do Espinhaço zone, and with indications of folds with a northeasterly trend, and thus parallel with the neighboring Archean ranges. It seems probable, therefore, that their first and strongest folding was due to a movement producing northeast-trending folds, and presumably involving the shale, sandstone, and limestone series of the São Francisco basin as well. The occurrence farther southward in the Paraná basin of a series very similar to this last, and which has been involved in the northeast folds of the adjacent Archean region, confirms this point of view. These rocks of the Paraná basin, like those of the São Francisco, are in general but slightly metamorphosed and are overlain, in the state of Paraná, by horizontal strata containing Devonian fossils (15). Though they have afforded no fossils, they are presumed to be of Cambrian or Silurian age.

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[1] Since the above-cited papers were written, a specimen has come to hand showing one of the types there discussed (the monazite-bearing schist of Sao João da Chapada), with a well-defined eruptive contact with quartzite.

This sedimentary series of the Paraná basin is abundantly injected with granite, which, for this region at least, fixes the age of the granitic eruptions as pre-Devonian. The granites are of various types (hornblendic, biotitic, and muscovitic), and doubtless several periods of eruption are represented among them, but presumably these were contemporaneous with, or posterior to, the orogenetic movements that produced the folding. The granites that occur quite abundantly in the areas occupied by the Minas series have not been studied, but it may be presumed that the above conclusions regarding age and periods of eruption will apply to them as well. Aside from the granites, these areas present frequent outcrops of basic eruptives of gabbroitic, diabasic, and peridotitic types, which, so far as observed, show signs of metamorphism (a certain amount of shearing and an uralitic alteration of the pyroxene), which may plausibly be attributed to the later movement of upheaval that involved the overlying sandstone as well. So far as observed, this last has not been affected by eruptive injections, nor do the auriferous veins so characteristic of the Minas series extend into it.

The sandstone capping of the Serra do Espinhaço zone presents, everywhere that it has been examined, great uniformity of aspect, except that the division into two series noted in the Paraguassú section has not been observed elsewhere. The conglomeritic character of the upper beds of this section is general throughout the range, and although in the Jequetinhonha and Doce sections the rock is in places somewhat metamorphosed, this apparently is not a sufficient reason for considering it as distinct. Another very general characteristic is the occurrence of diamonds, but these appear to be lacking, at least in workable quantities, in the extreme southern portion of the range in the vicinity of Ouro Preto, and also in the northern portion in the Jacobina region and beyond.[1] As already stated, there are reasons for suspecting that the Jacobina sandstone is more recent than that of the more southern portions of the range, but on this head nothing definite can be said. As to whether, with this exception and that of the lower beds of the Paraguassú region, the sandstones of the range are to be considered as constituting a geological unit, or not, must also remain in doubt, though I am personally inclined to an affirmative opinion.

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[1] The question of the mode of occurrence of the diamond in this range and other parts of Brazil will be discussed elsewhere.

The geological age of the characteristic rocks of the Serra do Espinhaço zone, and of the orogenetic movement that has given them their present attitude, must also remain in doubt. The most that can be said is that neither is as ancient as has hitherto been supposed, and apparently the Devonian can be taken as the extreme limit of age. This, however, includes the hypothesis, not in itself improbable, of a localization of the orogenetic movement, since the definitely known Devonian deposits of other parts of Brazil (in the states of Paraná, Matto Grosso, and Pará) were not affected by it. The other extreme age limit is the Cretaceous, but until the Jacobina section is examined, and the reputed find of fossils verified or disproved, this hypothesis can neither be accepted nor completely put aside. The hypothesis of a Mesozoic age (Cretaceous or pre-Cretaceous) is a seductive one, as this would bring into line, at least as regards age, the occurrences of the diamond in various parts of Brazil and in South Africa (17); but against this we have the assumed, though not definitely proven, relation of the horizontal limestones of the São Francisco valley and of the Rio Una, which, for the present at least, must be regarded as Palæozoic and newer than the Espinhaço uplift. All things considered, it seems to me most probable that the age, both of the rocks and of the uplift, will eventually prove to be the middle or late Palæozoic (Devonian to Permian).

The escarped margins of the Serra do Espinhaço zone is in many places very suggestive of faulting, and I was until recently inclined to admit the existence of fault lines of gigantic proportions. With a better knowledge of the adjacent regions, it seems probable that this feature may be due in great part to denudation under conditions of drainage and elevation different from the present ones. The range throughout a considerable portion of its length is bordered by well-defined denudation plains, some of which, as that of Joazeiro, are but slightly sculptured, while others are dissected by valleys excavated from 200 to 300$^{m}$ below the general level. In the region of the middle Jequetinhonha the conditions at one time, probably during a part of the Tertiary age, were such that an inland basin was filled up with horizontal deposits nearly to the level of the surrounding denudation plain, and later, through a rise in the land, both were dissected to a depth of 200 to 300$^{m}$. About the same amount of elevation is indicated by the coast Tertiary beds, by the Cretaceous strata near the Paulo Affonso cataract, and by the dissection of the denudation plain and horizontal Cretaceous (?) strata of the upper São Francisco basin; so that this movement may be taken to have been general and of approximately equal amount throughout the whole region. The Cretaceous strata of the Paulo Affonso region seems to have been laid down on a still older denudation plain, which must have stood at about the level of the sea, since the fauna contains a mixture of fresh-water and marine forms (cyprids and sharks). The denudation of the mountain zone was therefore effected by successive stages, and under different conditions of drainage and elevation; and to this circumstance are doubtless due many of its topographic characteristics.

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